Finite element analysis of multi-tiered reinforced fly ash wall using PLAXIS 3D

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ABSTRACT: A reinforced wall made by constructing offset at different elevation is called a multi-tiered wall. There are very few studies focusing on the behavior of multi-tiered walls. Also, the studies on the behavior of tiered walls utilizing industrial waste such as fly ash are limited. In India, only 60% of the total 176.74 million tons of fly ash generated was utilized during the year 2015-2016. In the present study, an attempt is made to understand the behavior of fly ash wall using finite element method so that fly ash can be utilized for construction of multi-tiered wall. Finite element analysis based software PLAXIS 3D was used. Tiered wall was modelled using fly ash as a backfill material. The properties of fly ash were determined using laboratory tests. Reinforced tiered walls were modelled by varying the number of tiers, offset distance and elastic stiffness of reinforcement. From the results it was inferred that fly ash acts as a good backfill material. Also, the reinforcement reduces the horizontal wall facia deformation. The behavior of wall was affected by number of tiers and offset distance. With increase in offset distance the factor of safety increases and horizontal displacement reduces. The displacement is also affected by number of tiers.

Keywords: Multi-Tiered wall, Fly ash, Geosynthetic reinforced wall, critical offset distance

1 INTRODUCTION

A tiered wall is constructed by providing offsets at different height of the wall. Provision of offset increases stability. However, the performance of the tiered wall depends upon many factors such as offset distance, number of tiers, type of reinforcement etc. Researchers have studied the behavior of wall in tiered configuration (Leshchinsky and Han 2004, Yoo and Kim 2008, Stuedlein et al 2012, Mohamed et al 2013 and Mohamed et al 2014). Yoo et. al. (2011) studied the internal stability of a multi-tiered wall and found that the critical offset distance beyond which tiers behave independently was lower than that provided by FHWA guidelines. Also the length of reinforcement played an important role in the stability of tiered wall. Fly Ash is the byproduct produced in the thermal power plants due to burning of coal. In India, only 60% of the total 176.74 million tons of fly ash generated was utilized during the year 2015-2016 (Dubey 2016). Using fly ash in the geotechnical engineering applications will help in minimizing the problem of fly ash disposal. Several researchers (Martin et al 1991, Ghosh and Subbarao 2007, Kim and Prezzi 2008, Pandian 2008, Lal and Mandal 2014 and Dutta and Mandal 2016) have found that fly ash acts as a good geotechnical engineering material. Studies conducted by Lal and Mandal (2012) to understand the feasibility of fly ash as a backfill material showed that fly ash can be used as a backfill material for reinforced wall. Kumar and Mandal (2017) studied the behavior of 2- tiered fly ash wall model using laboratory model test by varying the offset distance.

From the past studies, it is visible that the fly ash can be used as a good backfill material. However, numerical studies on fly ash wall in tiered configuration are very scant. To understand the behavior of fly ash wall, in this study an attempt has been made to understand the effect of offset distance, number of tiers, and elastic stiffness of reinforcement on the behavior of fly ash reinforced wall. Finite element analysis program PLAXIS 3D has been used to carry out the study.

2 FINITE ELEMENT ANALYSIS

2.1 *Finite element model*

The finite element model of 0.6 m height was modelled in PLAXIS 3D. Fly ash was used as backfill material. Table 1 shows the properties of fly ash used in the study. Geotextile was used as reinforcement. The properties of geotextile are shown in Table 2. The length of reinforcement was kept constant at 0.7H where H is defined as total wall height. The wrap around facing was provided on the wall such that the geotextile was wrapped on the face of wall and folded to give an additional overlapping layer. The length of overlapping layer was kept 0.4 Lr where Lr is the length of reinforcement. Since it is not possible to place two reinforcement one over the other in PLAXIS, a 2 mm thick fly ash layer was placed between the reinforcement layer and overlapping layer, as suggested by (Anubhav and Basudhar 2011). Figure 1 shows the Finite element model of single, 2-tier and 3-tier reinforced wall. The analysis was performed on single, 2-tiered and 3-tiered wall models by varying the offset distance from 0L to 0.6L where, L is the lower tier height.

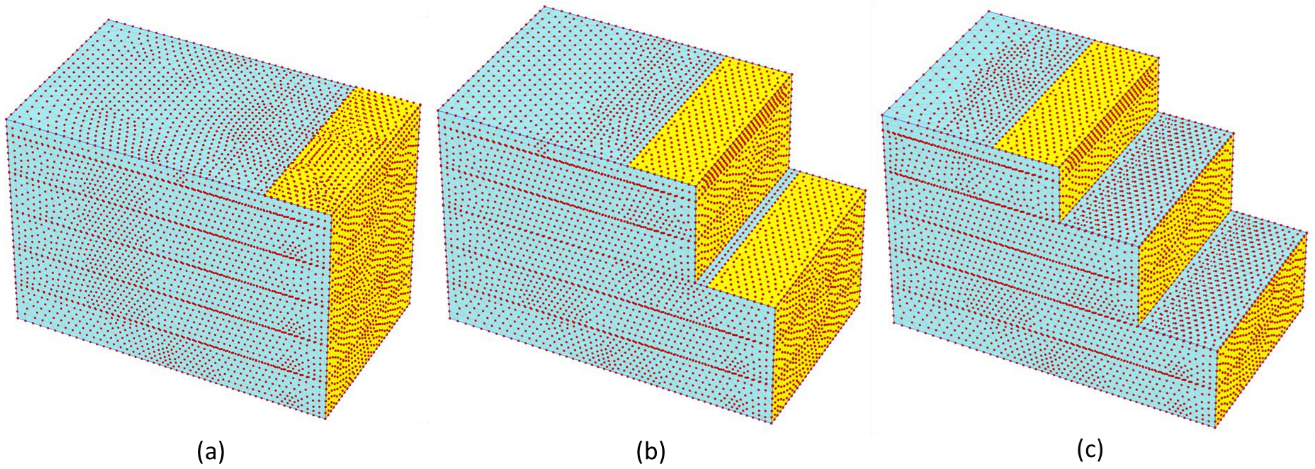

Figure 1. Finite element model of (a) single (b) 2-tier and (c) 3-tier reinforced wall

Table 1. Properties of Fly Ash

Properties	Values
Material Model	Mohr-Coulomb
Unit Weight (kN/m^3)	12
Elastic Modulus (kN/m^3)	4500
Poisson's Ratio	0.32
Cohesion (kN/m^2)	10
Friction Angle (°)	32

Table 2. Properties of Geotextile.

Properties	Values
Material Model	Elastic
Elastic Stiffness (kN/m)	160

3 RESULTS AND DISCUSSION

Factor of safety, horizontal wall displacement and total wall displacement were determined by varying the number of tiers and offset distance. A prescribed displacement of 50 mm was applied to determine the horizontal and total displacement on the wall model. The factor of safety was calculated from strength reduction factor. Figures 2 and 3 shows the total displacement diagrams of 2-tiered and 3-tiered wall model respectively. From the figures, it can be seen that the area of influence increases with the provision of offset which may cause reduction in stresses acting on the wall.

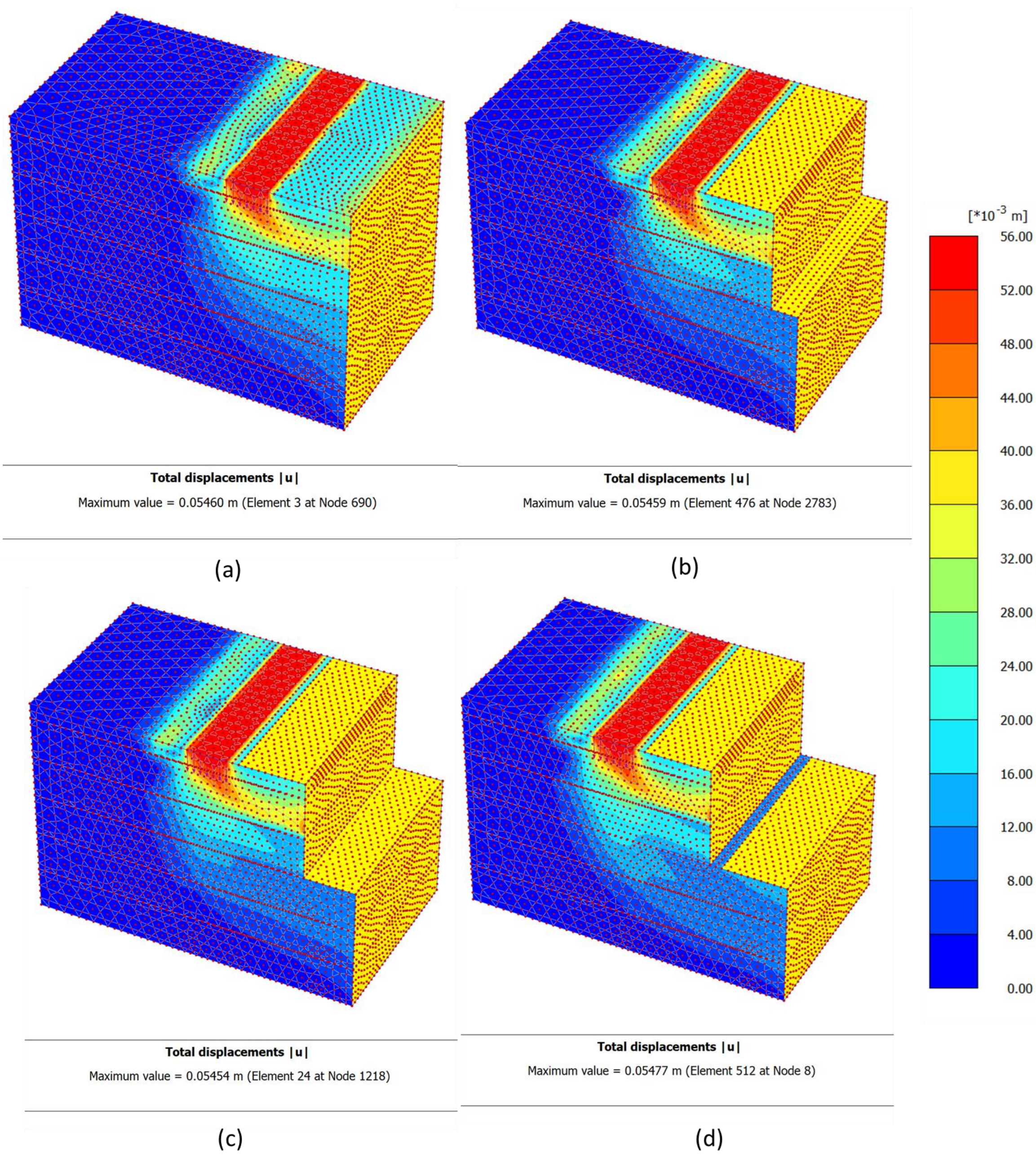

Figure 2. Total Displacements of two tiered wall model with offset distance of (a) 0L (b) 0.2L (c) 0.4L and (d) 0.6L

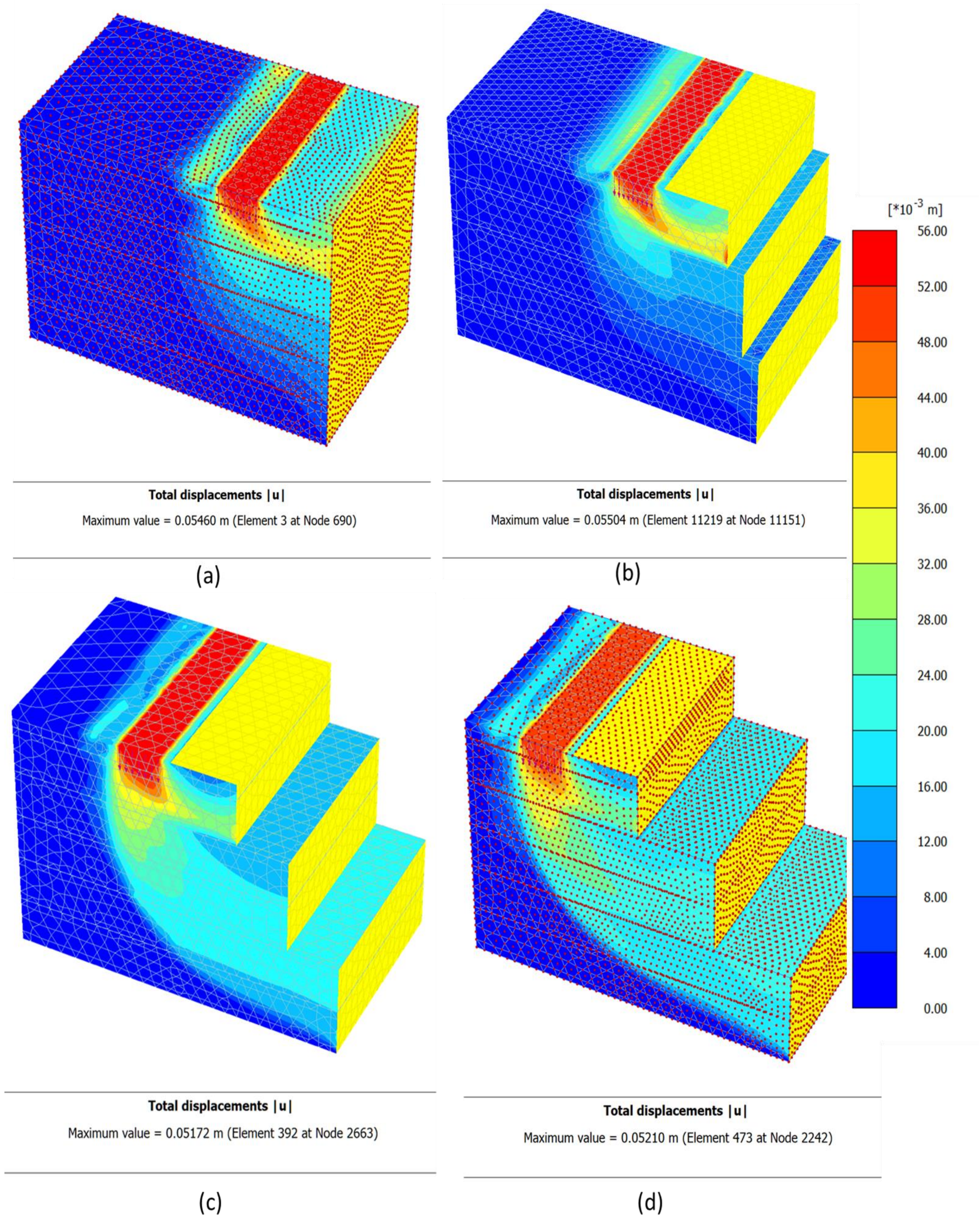

Figure 3. Total Displacements of three tiered wall model with offset distance of (a) 0L (b) 0.2L (c) 0.4L and (d) 0.6L

3.1 *Effect of offset distance*

Figure 4 shows the effect of offset distance on factor of safety, maximum horizontal wall displacement and maximum total wall displacement. From the figure it is evident that factor of safety increases with increase in the offset distance. Decrease in the overburden pressure due to the offsets might have caused the increase in the factor of safety. A reduction in maximum horizontal wall displacement was observed. However, no considerable reduction in the total displacement was observed. Since the total displacement is governed by prescribed displacement, the maximum total displacement values were similar for all the cases.

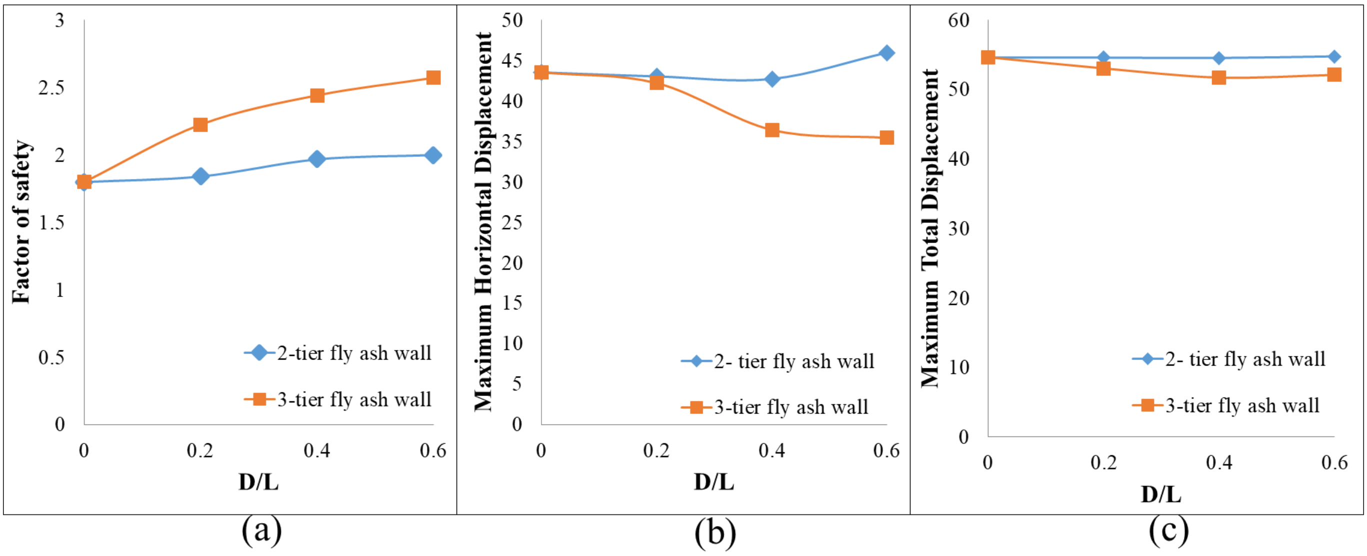

Figure 4. Effect of offset distance on (a) Factor of safety (b) Maximum horizontal displacement (c) Maximum total displacement

3.2 *Effect of number of tiers*

Figure 5 shows the effect of number of tiers on factor of safety, maximum horizontal wall displacement and maximum total wall displacement. For same offset distance, factor of safety increases with increase in the number of tiers of the wall model. Since the soil mass reduces with the increase in number of tiers, it may have led to the increase in the factor of safety. Also, a reduction in maximum horizontal wall displacement and total wall displacement was observed with an increase in the number of tiers.

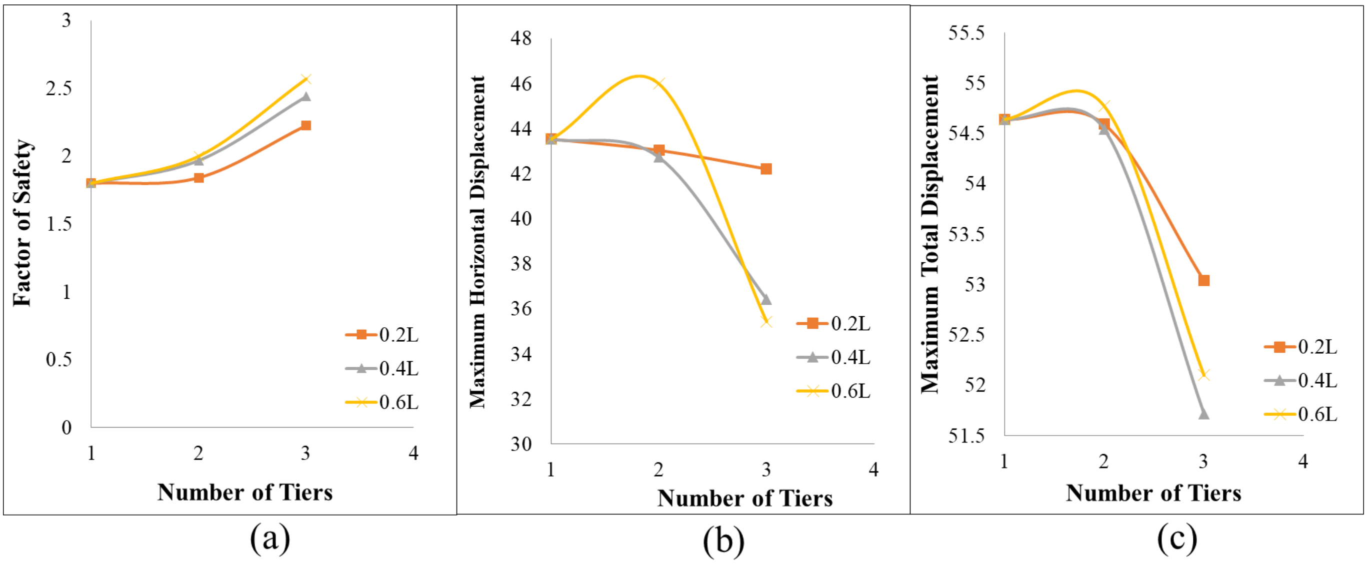

Figure 5. Effect of number of tiers on (a) Factor of safety (b) Maximum horizontal displacement (c) Maximum total displacement

3.3 *Effect of elastic stiffness*

Figure 6 shows the effect of elastic stiffness on maximum total wall displacement and maximum horizontal wall displacement of single wall. It was observed that the displacements of wall reduce with increase in the elastic stiffness of the reinforcement. However, the values become nearly constant after the elastic stiffness of reinforcement reaches 500 kN/m.

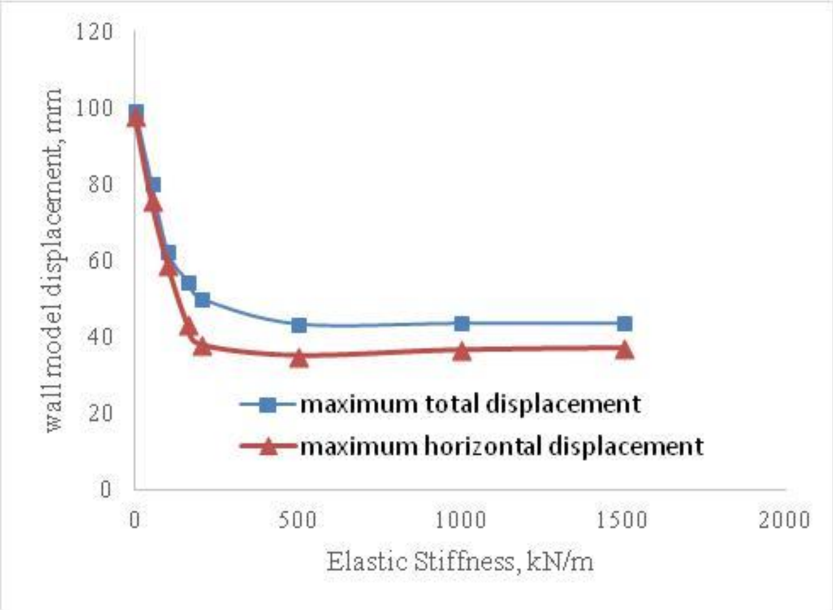

Figure 6. Effect of stiffness on displacement of single wall

4 CONCLUSIONS

In the present study, finite element analysis of tiered fly ash reinforced wall model was carried out using PLAXIS 3D. The effect of offset distance, number of tiers and elastic stiffness of reinforcement was determined on the factor of safety, and wall displacement. From the study, following conclusions can be made:

1. The geometrical parameters such as offset distance and number of tiers play an important role in the behavior of wall model.
2. The increase in the offset distance and number of tiers increases the factor of safety of the wall model. The factor of safety increased from 1.8 for single wall to 2.5 for 3-tier wall with offset distance of 0.6L.
3. The maximum horizontal displacement decrease with increase in the offset distance, number of tiers and elastic stiffness of wall model.
4. There was no considerable change in maximum total displacement with increase in offset distance and number of tiers, however, the increase in elastic stiffness reduced the maximum total displacement.

REFERENCES

Berg, R. R., Christopher, B. R. & Samtani, N. C. 2009. "Design of Mechanically Stabilized Earth Walls and Reforced Soil Slopes —Volume I.", FHWA Report No. FHWA-NHI-10-024.

Dubey, S. D. 2016 Report on Fly Ash Generation at Coal/Lignite Based Thermal Power Stations and Its Utilization in the Country for the Year 2015-16. Central Electricity Authority, New Delhi. pp. 1-30

Dutta, S. & Mandal, J. N. 2016. Numerical Analyses on Cellular Mattress – Reinforced Fly Ash Beds Overlying Soft Clay. International Journal of Geomechanics. 4016095-1-4016095–17.

Ghosh, A. & Subbarao, C. 2007. Strength Characteristics of Class F Fly Ash Modified with Lime and Gypsum. Journal of Geotechnical and Geoenvironmental Engineering. Vol.133(7), pp.757–766.

Kim B. & Prezzi, M. 2008. Evaluation of the mechanical properties of class-F fly ash. Waste Management.Vol. 28(3), pp. 649–59.

Kumar, A. & Mandal, J. N. 2017. Effect of Reinforcement on Multi-Tiered Fly Ash Wall. Procedia Engineering. Vol. 189, pp. 446 – 453

Lal, B. R. R. & Mandal, J. N. 2012. Feasibility study on fly ash as backfill material in cellular reinforced walls Electronic Journal of Geotechnical Engineering. Vol. 17, pp. 1637–1658.

Lal B. R. R. & Mandal. J. N. 2014. Behavior of Cellular-Reinforced Fly-Ash Walls under Strip Loading. Journal Hazardous, Toxic and Radioactive Waste Vol. 18(1), pp. 45–55.

Leshchinsky, D. & Han, J. 2004. Geosynthetic Reinforced Multitiered Walls. Journal of Geotechnical Geoenvironmental Engineering. Vol. 130(120), pp. 1225–1235.

Martin, B. J. P., Collins, R. A., Browning, J. S. & Biehl, F. J. 1991. Properties and Use of Fly Ashes for Embankments. Journal of Energy Engineering. Vol. 116(2), pp. 71–86.

Mohamed, S. B. A, Yang, K. H. & Hung, W. Y. 2013. Limit equilibrium analyses of geosynthetic-reinforced two-tiered walls: Calibration from centrifuge tests. Geotextile and Geomembranes. Vol. 41, pp.1–16.

Mohamed, S. B. A., Yang, K. H., & Hung, W. Y. 2014. Finite element analyses of two-tier geosynthetic-reinforced soil walls: Comparison involving centrifuge tests and limit equilibrium results Computers and Geotechnics Vol. 61, pp. 67–84.

Pandian, N. S. 2004. Fly ash characterization with reference to geotechnical applications, Journal of the Indian Institute of Science. Vol. 84(6), pp. 189–216.

Park, I. J., Yoo, C. & Jang, Y. S. 2011. Internal stability of geosynthetic-reinforced soil walls in tiered configuration. Geosynthetics International. Vol. 18(2), pp. 74–83.

Brinkgreve RBJ, Kumarswamy S & Swolfs WM. 2017. Plaxis 3D manual [computer software]. PLAXIS bv, Delft

Stuedlein, W., Allen, T. M., Holtz, R. D. & Christopher, B. R. 2012. Assessment of Reinforcement Strains in Very Tall Mechanically Stabilized Earth Walls. Journal of Geotechnical and Geoenvironmental Engineering. Vol. 138(3), pp. 345–356.

Yoo, C. & Kim, S. B. 2008. Performance of a two-tier geosynthetic reinforced segmental retaining wall under a surcharge load: Full-scale load test and 3D finite element analysis. Geotextile and Geomembranes. Vol. 26(6), pp. 460–472.

Yoo, C., Jang, Y. S. & Park, I. J. 2011. Internal stability of geosynthetic-reinforced soil walls in tiered configuration. Geosynthetics International. Vol. 18(2), pp. 74–83.